THE DOSE EQUIVALENT EQUATION

H.O. Wyckoff
International Commission on Radiation Units and Measurements
Washington, D.C. 20014

In 1962, discussions between the International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (ICRP) resulted in the formulation of a statement on dose equivalent, and this statement with minor modifications was utilized in subsequent publications of the Commissions.

At the time the statement was first published it was noted that, "although this statement does not cover a number of theoretical aspects (in particular the physical dimensions of some of the quantities) it fulfills the immediate requirement for an unequivocal specification of a scale that may be used for a numerical expression in radiation protection". One might view the dose equivalent as having the dimension of absorbed dose, being a biophysical quantity or representing risk and therefore physically dimensionless. A brief discussion of the reasons for each interpretation is included. The interpretation recommended by the ICRU -with ICRP concurrence- is presented.

Introduction

The dose equivalent is a quantity determined in an organ or tissue of the body of a person and related to the presumed risk of radiation induced injury to that organ or tissue. The use of this quantity is limited to radiation protection applications and should not be used for high level accidental exposures. It is defined by the equation

$$\underline{H} = \underline{D}\ Q\ N$$

where $\underline{D}$ is the absorbed dose determined at the site of the presumed radiation induced injury,

Q is a modifying factor related to radiation quality at the site and whose numerical values are given in terms of the collision stopping power in water in figure 1 and,

N represents the product of all other modifying factors.[1]

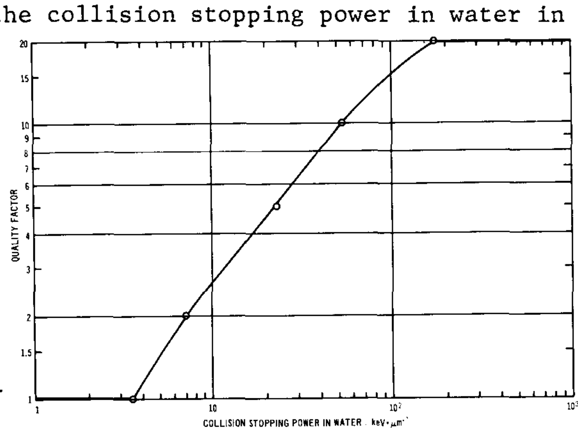

Fig. 1 The quality factor as a function of the collision stopping power in water.

When $\underline{D}$ is in rads, $\underline{H}$ is in rems. This definition is adequate for practical determinations, but does not spell out the meaning of $\underline{H}$ and in particular its dimensions. The dose equivalent could be, among other things, either a purely physical quantity, a biophysical quantity, or a representation of the risk of radiation induced injury and therefore dimensionless. Each interpretation has its following within the scientific community. These three interpretations will be discussed in the present paper and the ICRU recommended interpretation outlined.

A Physical Quantity

A physical quantity denotes a physical entity or concept used for the precise description of a phenomena and defined so as to be measurable. Proponents of a purely physical interpretation of dose equivalent view the modifying factors Q and N as purely physical factors. They point out that Q is related to the radiobiological effectiveness (RBE) which is merely the inverse ratio of absorbed doses of different types and/or energies of radiation that produce the same biological effect. It is recognized that the magnitude of the RBE is obtainable experimentally only for large absorbed doses and absorbed dose rates and that its magnitude may change with absorbed dose and absorbed dose rate. Thus, the value of Q should be obtained ideally by extrapolation of observed RBE values to the absorbed dose and absorbed dose rates encountered in the radiation protection area. Such an extrapolation will not modify the dimensions so that Q is dimensionless.

Other factors that might be included in N are obtained in a similar fashion. For example, if one were to incorporate an absorbed dose rate factor, it would be obtained from the inverse ratio of the absorbed doses at different rates that would produce the same effect. This factor is also dimensionless. Again, these experimental data obtained at high doses ideally would be extrapolated to the absorbed doses of interest for radiation protection.

With such an interpretation, Q and N are dimensionless and the dimensions of D and H are identical (energy/mass). In this case, the units of D and H are the same. This means that both D and H can be expressed in rads or joules per kilogram.

A Biophysical Quantity

Proponents of this interpretation agree that the magnitude of Q and N are inferred from physical measurements-- for example, the value of Q being inferred from the inverse ratio of absorbed doses required to produce the same biological effect. However, they point out that the magnitude of the ratio depends upon the biological end point. In their view, this is a different type of situation than those in the purely physical area. For example, the effective current for an alternating voltage wave form is equal to the constant current required to produce the same heating in an electrical resistance. Such a definition gives an unequivocal relation between the two electric currents because a particular physical effect has been chosen for the relation. However, the value of the RBE (and presumably that of Q inferred from it at low dose and dose rate) depends upon the biological end point. While the value of Q for a given collision stopping power in water is currently assumed to apply to all tissues or organs, there are as yet insufficient data to determine whether this is actually true.

The proponents of this view point out also that a modifying factor, n, is used for radionuclides deposited in bone which is likely to be related "among other things to non-uniform spatial distribution of absorbed dose, the essentiallity of the damaged tissue and the radiosensitivity of the particular type of irradiated cells".[2] Such a factor is not used for other tissues even though the tissues may be exposed to a similar non-uniform spatial distribution of absorbed dose. Incidentally, "absorbed dose" is used here because it is part of a quotation. A better term would be "specific energy imparted".

Thus, those who believe that the dose equivalent is a biophysical quantity, base their argument on the requirement for the specification of the biological end point for the determination of the modifying factors. To reinforce their argument, they point out that the value of the dose equivalent may be different in different organs or tissues even though the purely physical parameters are identical.

A Risk

ICRP Publication 14- a report of two task groups to the parent commission- contains a discussion of how one might set relative permissible levels to the different tissues or organs of the body.[3] This scheme requires 1) a commonly agreed upon scale for "hurt or suffering" resulting from radiation damage of different tissues or organs and 2) the relative sensitivity of the various organs or tissues expressed as the ratio of doses required for equal "hurt or suffering".

If the permissible levels were based on such a scheme, the risk from a given dose equivalent in a particular organ would be proportional to this dose equivalent divided by the permissible level for that organ. While such a scheme for setting permissible levels is not now in effect, primarily because there is no generally accepted scale of "hurt or suffering", the dose equivalent to a given organ is presumed to be proportional to the radiation risk in that organ. However, for equal dose equivalents in different organs the risk will generally not be the same.

Discussion

It is generally assumed that the dose equivalent to a particular organ or tissue is proportional to the risk of radiation induced injury for that organ. However, there is no commonly agreed upon scale of "effect" for all organs and tissues, so that the risk in any one organ may not be the same as for another organ even though their dose equivalents may be the same. For this reason, the dose equivalent equation cannot be considered generally to give an indication of the risk.

A fundamental assumption in the current use of the dose equivalent equation is that the value of the quality factor is independent of the organ under consideration and of the biological end point. Conceptually it primarily depends upon experimentally determined values of RBE. Thus, this factor is dimensionless. The magnitude of Q depends upon an agreed relation with the collision stopping power in water and is evaluated at the site of interest. The value of any modifying factor that might be included under N is also envisaged as being obtained from the ratio of the absorbed doses required to produce the same effect and is therefore also dimensionless. With these assumptions, and as the equation is currently used, it becomes a purely physical equation and the units of absorbed dose and dose equivalent may be the same.

One could think of H as either a weighted value of the absorbed dose or the absorbed dose of a reference radiation that would produce the same effect. If the latter is chosen, the proper term for H would be the "equivalent absorbed dose" of a reference radiation. It must be remembered, however, that the values of Q are merely estimates of the true value. Furthermore, biological variability has not been factored into these values. Thus, the same effect may not be presumed to be produced by an equivalent absorbed dose of a reference radiation. The ICRU, with ICRP concurrence, has agreed to retain the name "dose equivalent" for H and to treat the factors Q and N as dimensionless weighting factors.[4]

While both the dose equivalent and the absorbed dose may be given in either rads or joules per kilogram, the ICRU, with ICRP concurrence, has recommended that a specially named unit -the rem- be used for dose equivalent.[4] The redundancy resulting from the use of this special unit is deemed important by these commissions because the employment of the same unit for both absorbed dose and dose equivalent might lead to erroneous decisions in the matter of radiation safety. They point out that this redundancy conforms with the general safety policy in this technical area and is a continuation of established practice.

References

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2. International Commission on Radiological Protection, ICRP Publication 9, Recommendations of the International Commission on Radiological Protection, 1965. (Pergamon Press, Oxford, 1966)

3. International Commission on Radiological Protection, ICRP Publication 14, Radiosensitivity and Spatial Distribution of Dose. (Pergamon Press, Oxford,1969)

4. International Commission on Radiation Units and Measurements, Supplement to ICRU Report 19, Dose Equivalent, (International Commission on Radiation Units and Measurements, Washington,1973)